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# Measurement of voltage level output by magnetic tunneling junction by rectification of RF signals



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# Measurement of voltage level output by magnetic tunneling junction by rectification of RF signals

**Dr. Thomas Meitzler**
**Dr. Elena Bankowski**
**Dr. Andrei Slavin**
**Steven Zielinski**

**4/13/2011**

**Abstract**

In this experiment, the DC voltage output of a magnetic tunneling junction (MTJ) was measured. This was accomplished using both a broadband log periodic antenna and broadband ridge horn antenna as a radio frequency (RF) source. Transmission frequencies ranged from 1 to 6 GHz at varied power levels of 0 to 20 dBm. The signal was received by a coplanar waveguide antenna. A MTJ rectified the RF signal to a DC voltage.

## Introduction

The device studied in this experiment operates on the quantum phenomena of electron spin. Microwaves are received by the coplanar waveguide antenna. These signals are passed into a magnetic tunneling junction. These microwaves cause the vector of magnetization of the free layer of the MTJ to precess. Resonance frequency of the free layer is controlled by a tunable external magnet. As the orientation of magnetization of the free layer to fixed layer changes, the generated resistance oscillates with time. A DC voltage results from the changing resistance and spin-polarized current.

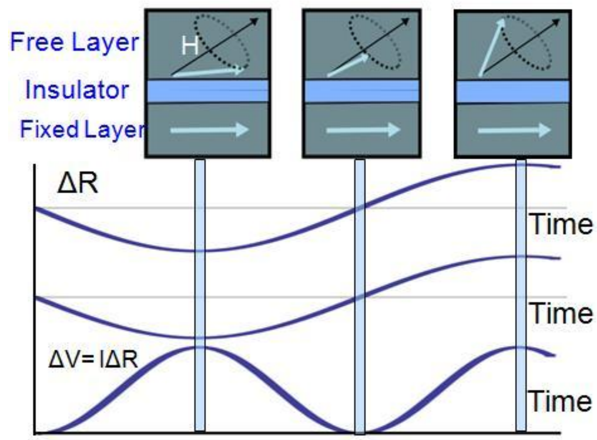



***Figure 1 – DC voltage produced by microwave input and changing resistance***

The CPW is inserted in a brass enclosure. The CPW connects to the MTJ. The back of the MTJ is grounded to the enclosure. Through wire bonds, it outputs DC voltage to the SMA pin. In the side of the case resides a permanent magnet attached to a set screw. Turning the set screw tunes the magnetic field which changes the resonance frequency of the MTJ. Electrostatic discharge (ESD) diodes are also located inside the enclosure. A black Duroid cover, which does not impede microwave transmission, protects the internal components (removed for pictures).

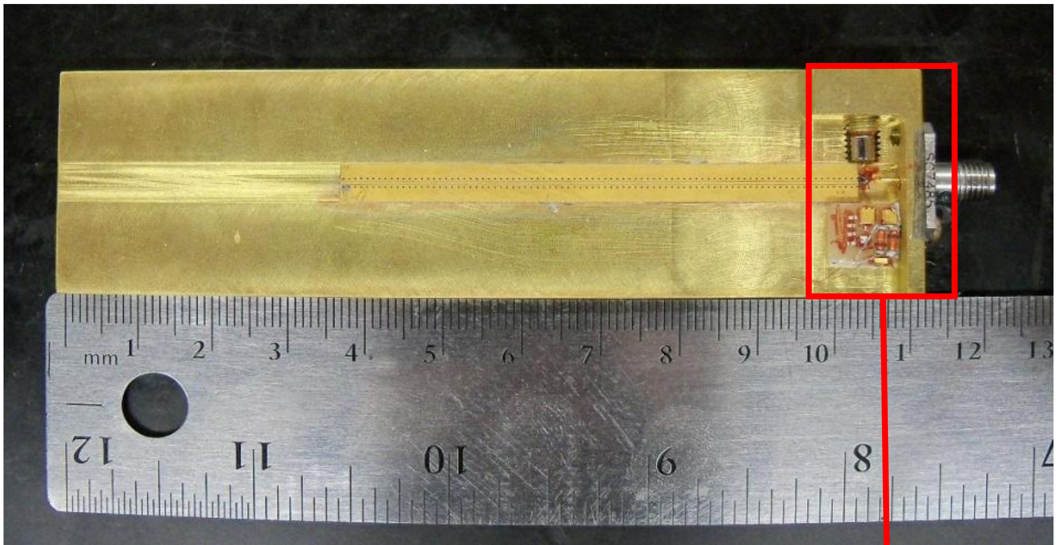


***Figure 2 – Spintronics Detector***

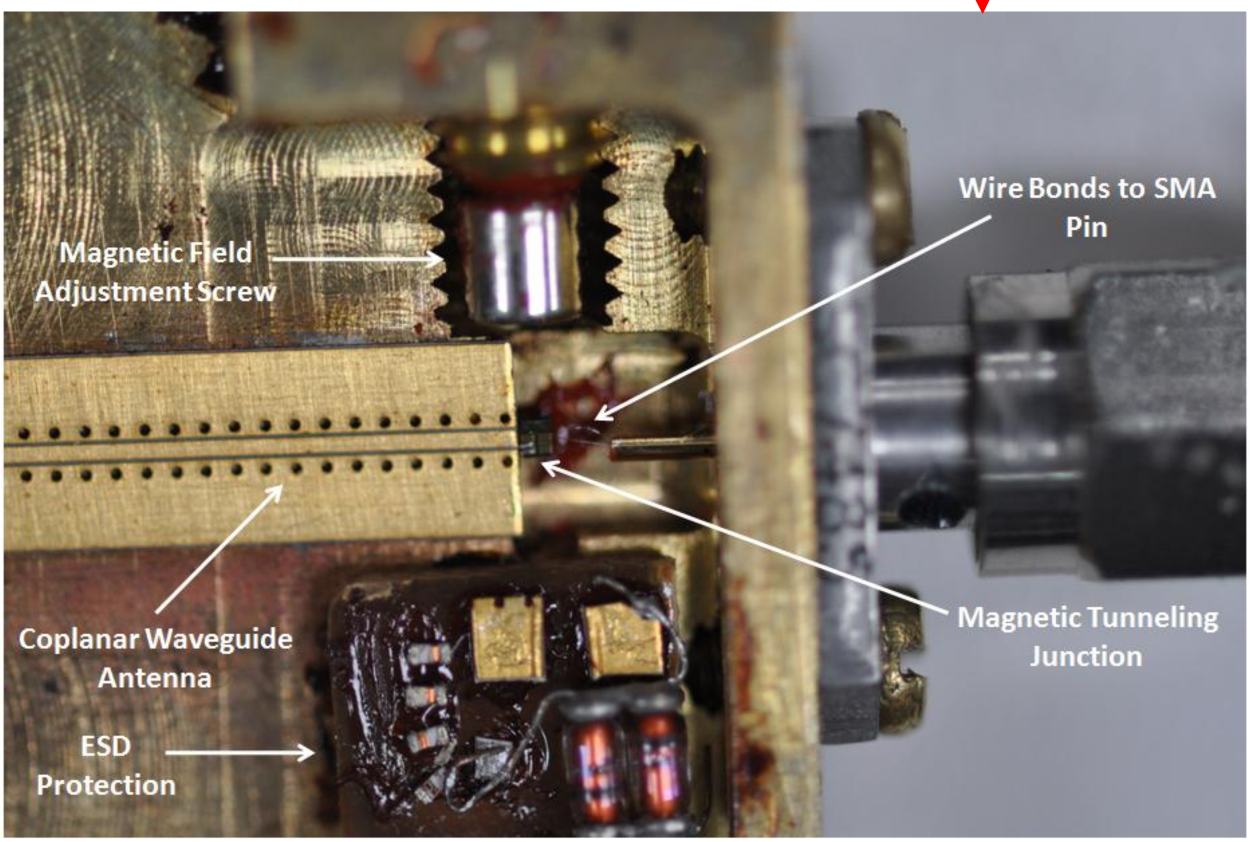
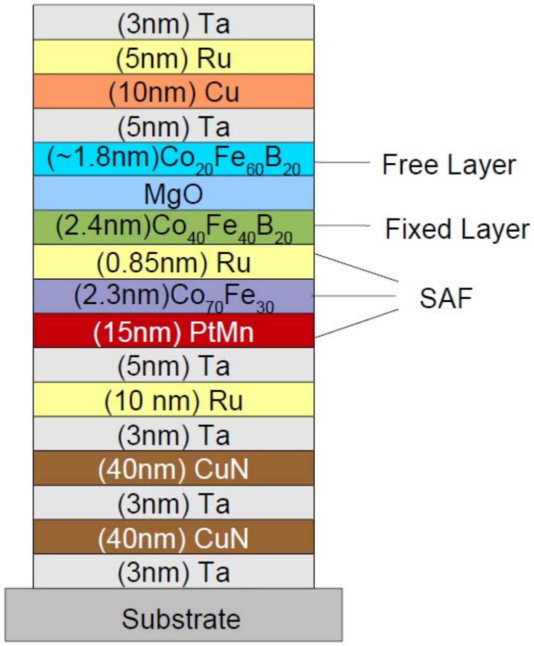



***Figure 3 – Spintronics Detector (Exploded View)***

The material composition of the MTJ consists of multiple layers. The $Co_{20}Fe_{60}B_{20}$ acts as the free layer and $Co_{40}Fe_{40}B_{20}$ behaves as the fixed or pinned layer. These two layers are separated by a tunneling barrier made of MgO.



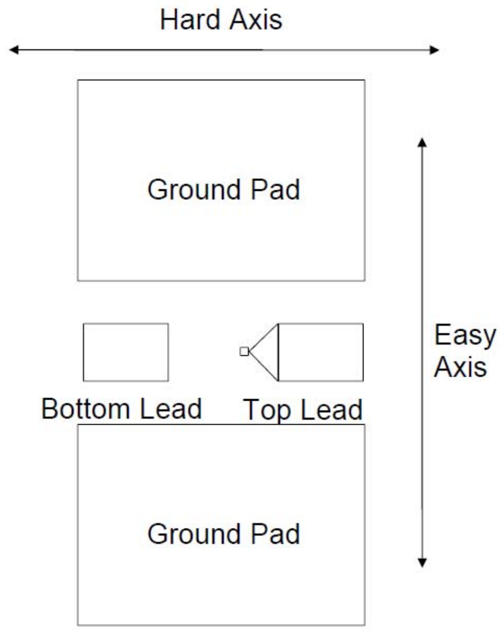




***Figure 4 – MTJ Composition*** ***Figure 5 – MTJ electron path***

**Experimental Setup**

Equipment preparation began by testing our antennas. Two different types of antennas were used in this experiment, periodic log and horn ridge. The radiation patterns for each were recorded inside an anechoic chamber encased in a Faraday cage.

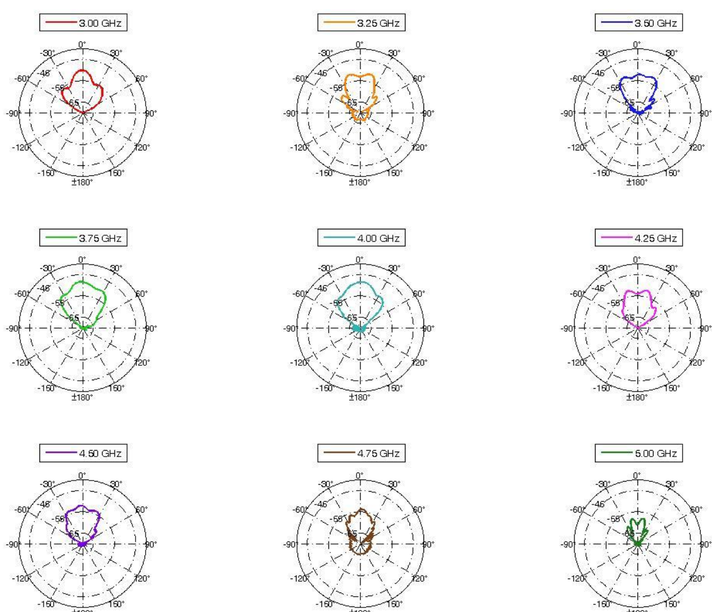



*Figure 6 – Kaltman Antenna Radiation Pattern*

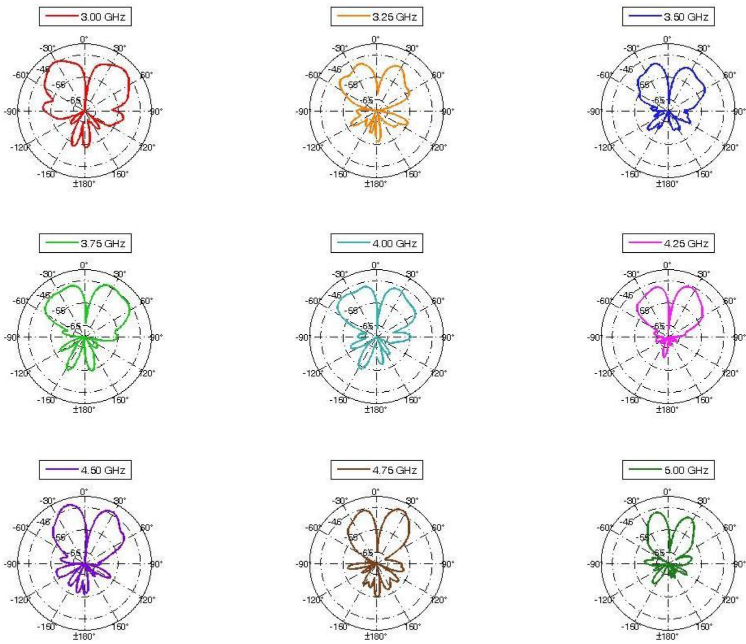



*Figure 7 – Horn Ridge Antenna Radiation Pattern*

Radiation pattern for the Kaltman antenna was as expected. However, the horn ridge antenna radiation pattern indicates the antenna is malfunctioning. On the main beam of the antenna (0 degrees), the antenna has zero power. Since this is a directional antenna, maximum power should be achieved at 0 degrees. Currently, the antenna is continuing to be diagnosed to resolve the issue.

The complete measuring circuit including the antennas, nanovoltmeter, and function generator was tested using an Agilent 8474 GaAS microwave detector. The function generator produced a signal to a transmitting antenna. The transmitted signal was received by another antenna and passed to the GaAS detector. The detector rectified the voltage which was read by the nanovoltmeter. The measuring circuit was tested using two different antenna configurations: two Kaltman antennas; one Kaltman and one horn ridge. Since the horn ridge was not working, no data was recorded from this test for that antenna.

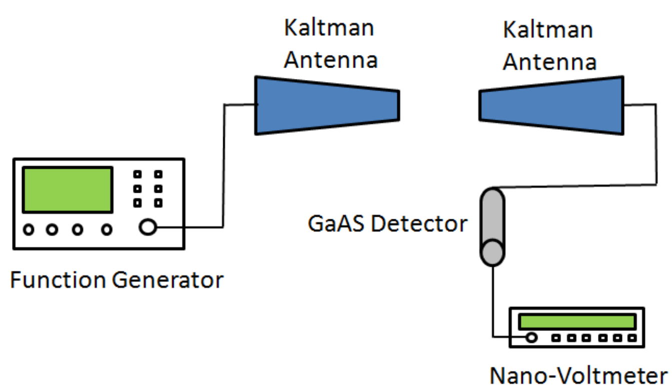



*Figure 8 – Kaltman to Kaltman measuring test circuit*

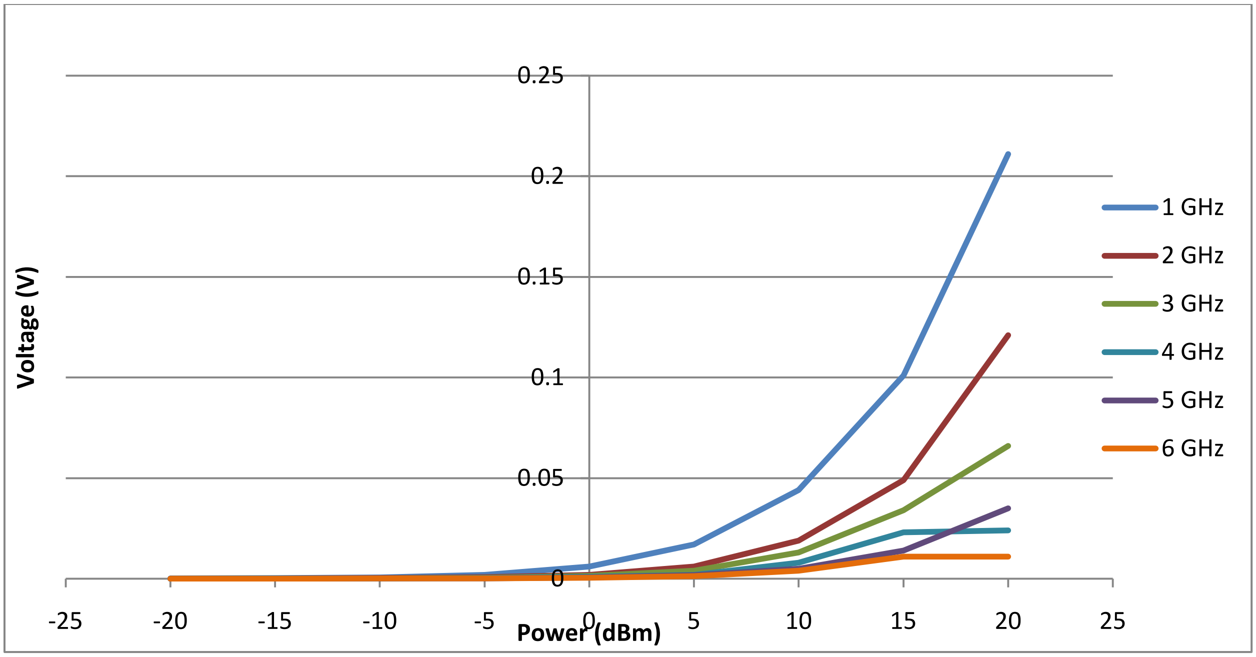



*Figure 9 – Kaltman to Kaltman GaAS data*

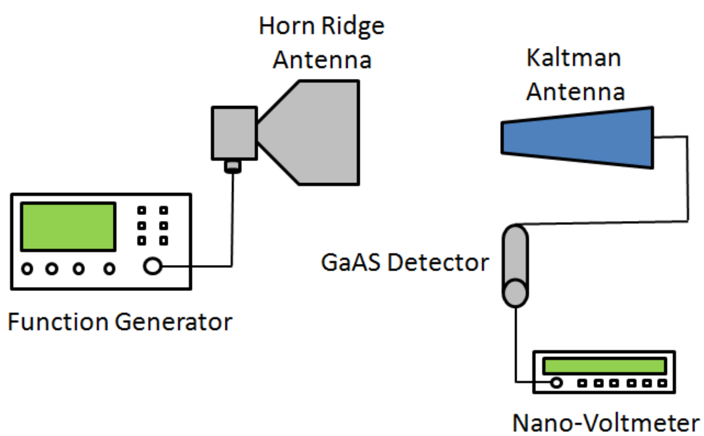



*Figure 10 – Horn Ridge to Kaltman measuring test circuit*

**Results**

Unfortunately, no results have yet been achieved from the spintronics detector. This is primarily due to the failure of the detector. The first prototype device was received University of California (UCI) at the beginning of January. Initially, inability to receive DC voltage output was assumed to be problems with the testing equipment or testing procedure. Using the GaAS diode detector, the testing equipment was confirmed as operational. Correspondence with UCI ensured testing procedure was correct. By the middle of January, the device was returned for inspection. UCI determined that the wire bonds connecting the MTJ to the SMA pin had been broken due to shipping. The device was repaired and returned to TARDEC at the beginning of February. Included with the device was a bias tee and external ESD protection because the internal ESD circuit had failed during manufacturing. Again, no DC voltage

was detected in the TARDEC lab. UCI insisted the device was tested and working before shipment. They instructed that the ESD and bias tee be removed for a direct resistance measurement of the spintronics detector. The detector was found to out of resistance specification and declared dead. A shipment of 10 detectors was due at the end of February which was to be delivered by a technician from UCI. These detectors were to include many improvements including internal ESD, removable cover for component inspection, and use of updated wire bonding methods from MTJ to SMA pin. Since this shipment was impending, UCI recommended not sending back the broken detector and wait for the shipment of new detectors. Unfortunately, these detectors were not able to be shipped due to back order on required materials and delays in fabrication at the UCI machine shop. The devices were then promised for the second week of March along with the UCI technician. This shipment was suspended when the UCI technician became unable to travel due to sudden severe health concerns. UCI did not have another technician trained in spintronics or had passed TARDEC security screenings. Because of this, it was determined to send Steven Zielinski to UCI to observe testing procedures and also receive theory of device operation.

Many improvements to the experimental setup were made during the process of diagnosing the problems with the spintronics detectors. To improve transmission clarity, a custom cable was designed and fabricated to connect the nanovoltmeter to the detector. This provided a direct connection from the proprietary Agilent connector to BNC. The original Agilent cable had spade terminals. These were attached to a BNC adapter via screw down lugs. The custom cable reduced losses due to the connector conversions. It was tested using the GaAS diode detector for continuity and clarity.

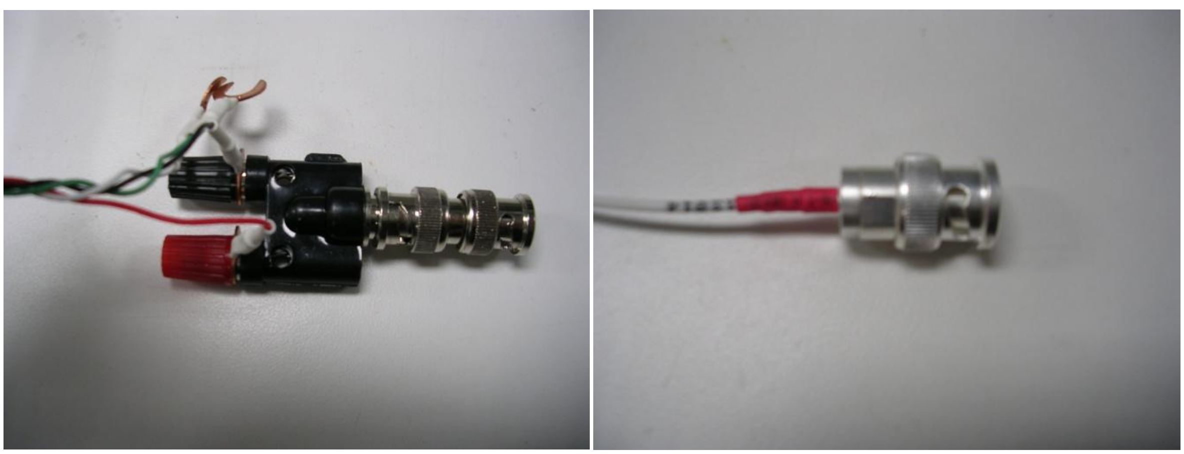


*Figure 11 – Left: UCI recommend method. Right: Custom BNC cable*

Another improvement was aimed at reducing both internal and external electromagnetic radiation. An anechoic chamber was built from specialized foam to reduce internal reflections. The chamber was wrapped in a Faraday cage and attached to ground to shield external radiation. The chamber was tested by placing a cellular phone inside. The phone would not ring inside the chamber, but immediately received service when removed.

*Figure 12 – Left: Anechoic chamber/Faraday cage. Right: Internal view of anechoic chamber*

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